HOW2POWER TODAY
Your Power Design Newsletter

Exclusive Technology Feature

ISSUE: April 2021

Developing A 25-kW SiC-Based Fast DC Charger (Part 1): The EV Application

by Oriol Filló, Karol Rendek, Stefan Kosterec, Daniel Pruna, Dionisis Voglitsis, Rachit Kumar and Ali Husain, ON Semiconductor, Phoenix, Ariz.

The fast dc charging market is thriving. Along with the acceleration in the adoption of electrical vehicles (EVs), the demand for fast charging infrastructure is increasing. Growth projections range from 20% to 30% CAGR for the next five years. If you are an application, product or design engineer working in the power electronics field, sooner or later you could be involved in the design of one such novel charging system.

A basic question might arise here, especially if it is the first time you are facing such a challenge. How and where should I begin? What are the key design considerations and how should I address them?

ON Semiconductor's EMEA Systems Engineering team is gearing up to help designers address such a challenge as we'll demonstrate by designing and developing a 25-kW fast dc charger based on SiC power integrated modules (PIMs).

Developing this type of high-power battery charger requires a diverse skillset. ON's Power Systems Section team, which is based in Piestany, Slovakia, leads the project coordination on this design and undertakes all the activities related to hardware development. Karol Rendek as power systems applications manager and Stefan Kosterec as senior power systems application engineer do the heavy lifting. Both of them are seasoned power electronics design engineers, well-versed in high power conversion applications.

The firmware and software development are being performed by the Motor and Power Conversion Control Section team, based in Munich, which includes Daniel Pruna as team leader and Dionisis Voglitsis and Rachit Kumar as application engineers. The team brings years of experience in control and algorithm development of power converters and motor drives.

In this article series we will walk through the development process of the dc charger, addressing a different topic in each installment. We will highlight the key challenges, tradeoffs and compromises made, and show how to design, build and validate such a system from scratch. We know the design journey is not a straight one, and the best way to move forward is to get up and running and iterate fast. Here in part 1, we'll describe the structure of the fast EV charger and define its key electrical specifications.

Fast DC Charger—What Are We Building?

In the e-mobility ecosystem, dc chargers provide "fast" and "ultrafast" charging capabilities, in contrast with slower ac chargers. In essence, EV chargers convert the ac power from the grid into dc power suitable for delivery into the batteries of the EVs. The power conversion in dc charging is handled outside the EV ("off-board") and then delivered to the vehicle with power levels ranging from below 50 kW to greater than 350 kW (with even higher levels in development).

Higher power dc chargers are typically built in a modular fashion, where power blocks of 15 to 75 kW (and above) are stacked together (Fig. 1) in a single cabinet. In general, output voltages of dc chargers range from 150 V to north of 1000 V, covering both the 400-V and 800-V common EV battery levels. Chargers may be optimized for the higher or lower voltage end.

The architecture of such power blocks is as follows: an ac-dc boost converter with power factor correction (PFC) at the front end, followed by a dc-dc stage that provides isolation between the grid and the load (battery of the EV) and regulates the voltage and current at the output (Fig. 1 again). The system may be bidirectional as well (particularly at lower power), and thus the topology and design should account for it.

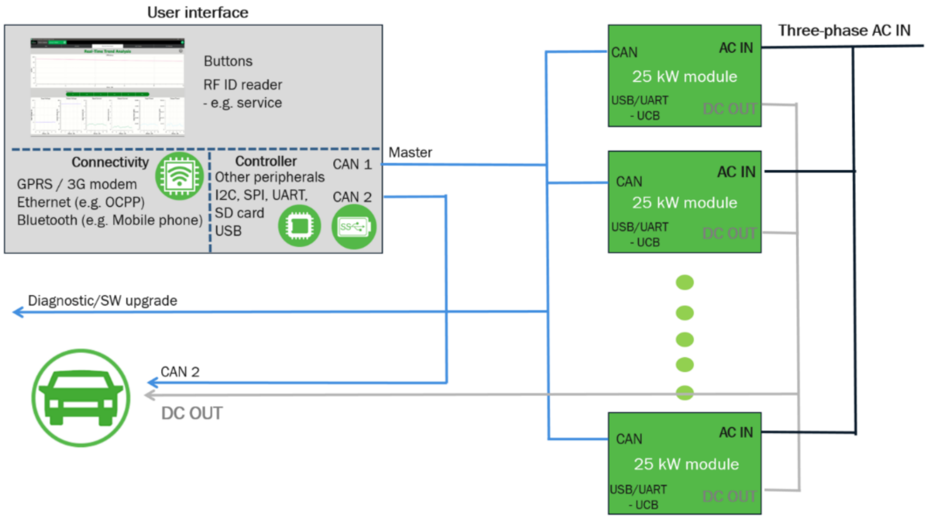

Fig. 1. Overview of the main blocks in a fast dc charger.

On Semiconductor's team is developing a 25-kW dc charger with bidirectional capability. The system shall cover a wide output voltage range, being able to charge EVs with both 400-V and 800-V batteries, optimized for the higher voltage level. The input voltage is rated for EU 400-Vac and U.S. 480-Vac three-phase grids. The power stage shall deliver 25 kW over the 500-V to 1000-V voltage range. Below 500 V, the output current will be limited to 50 A, derating the power, in alignment with profiles of dc charging standards such as CCS or CHAdeMO (Fig. 2).

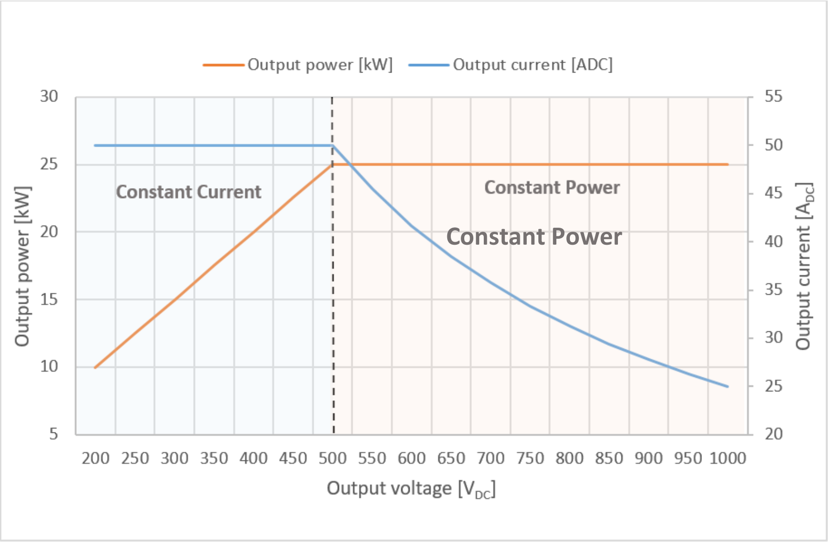

Fig. 2. Power and current profile of the 25-kW dc charger power stage. The current is limited to 50 A below 500 V.

Regarding communication ports, the board will provision isolated CAN, USB and UART infrastructure for external interfaces (between power blocks, charger system controller, vehicle, service and maintenance). Overall, the design will follow guidelines from the IEC-61851-1 and IEC–61851-23 standards for EV charging. The table below summarizes the system requirements.

Table. Requirements for the 25-kW fast dc charger.

Complete system PFC + dc-dc converter		
AC input	Voltage input rating	Three-phase 400 Vac (EU), 480 Vac (US)
	Max. input current	40 A
	Frequency	50/60 Hz
	Power factor	>0.99
	Efficiency	>96%
DC output	Output voltage	200 V to 1000 V
	Max. output power	25 kW
	Max. output current	50 A
Protections	Output	OVP, OCP, SC
	Input	UVP, OVP, inrush current
	Internal	Desat (gate driver), thermal (NTC on power device)
User Interface	Push buttons	Yes
	GUI	Yes. STRATA based GUI for system evaluation
Communication buses	Internal	SPI, I^2C
	External	Isolated CAN, USB, UART
Environmental	Operating temperature	0°C to 40°C
Max. mechanical dimensions	PCB	450 x 300 x 280 mm (PFC and dc-dc stacked)
Standards	Regulation	Following guidelines described in EN55011 Class A. Will not be tested.
	EV systems	Following guidelines described in IEC 61851. Will not be tested

The Development Process

Our team follows the logic of power conversion hardware development processes. The work starts with the definition of the actual dc charger power stage. This is based on the requirements for the application, in our case summarized in the table. These are in accordance with the needs of the market and follow the guidelines of IEC-68515. These requirements help the team understand what target they need to shoot for.

The first feasibility studies help validate the initial requirements and assumptions. These will be integrated as part of the system design that encompasses (in the scope of this project) hardware, software, thermal management and mechanical design, prototyping and validation. All the essential system variables and most of the critical compromises and trade-offs for the solution happen during the feasibility studies.

These tasks and sub designs are carried out with multiple iterations, where outputs and assumptions from one part are fed back to another. Two of the main design activities that provide significant outputs to move forward are:

- Power simulations with SPICE models
- Control simulation using MATLAB and Simulink.

Power simulations are crucial to confirm the assumptions on working voltage and currents, losses, cooling requirements, and selection of power and passive components, among others. Once an implementation plan is ready, control simulations, including the power parameters, are carried out to confirm that the control loops can be effectively executed with the power design.

After proving the design with the power and the control simulations, the green light is granted to draw the schematics, layout the PCB and manufacture prototypes. Once boards are available, hardware bring up, functionality testing and system characterization are carried out.

That was a simplified summary of the design process we will be describing in this series. Developing a 25-kW EV dc charger from scratch entails more than that, and the most valuable takeaways will come as we solve the challenges and issues that come along the way.

What Is Coming?

In subsequent parts of this article series, we will be taking a closer look at some of the design and validation stages. The following topics will be addressed:

- Solution overview
- The three-phase PFC rectification stage
- The dual active full-bridge dc-dc stage
- Control algorithms, modulation schemes and feedback
- Gate driver system for SiC power modules
- Auxiliary power units for 800-V bus
- Thermal management.

For any questions, about this part 1 or upcoming parts of this series, write to the authors at this email.

About The Authors

Oriol Filló serves as a solution marketing engineer for industrial applications at ON Semiconductor. He is responsible for the marketing strategy of industrial solutions, focusing on robotics and energy infrastructure. He has developed his career in the electronics industry with a focus on power and control, and gathered experience in industrial, IoT and automotive applications.

Prior to joining ON Semiconductor in 2019, Oriol worked at Industrial Shields and PRAX Inductive Components in technical sales and business development roles, where among others, he propelled growth of the export business. Oriol received an engineering degree in energy engineering and a M.Sc. in industrial automation systems and industrial electronics from Universitat Politècnica de Catalunya. Oriol also holds a master in management from EADA Business School.

Karol Rendek is an applications manager at the Systems Engineering Center at ON Semiconductor. Karol joined ON Semiconductor in 2020. Previously, he spent nine years working as hardware engineer, system engineer and project manager in development of embedded systems, Class D amplifiers, rolling stock control and safety systems and industrial electric vehicle chargers. Karol has Master's degree and Ph.D. in Microelectronics from Slovak University of Technology in Bratislava. He spent three years during his Ph.D. study focusing on low frequency noise analysis of GaN HEMT transistors.

Stefan Kosterec is an application engineer at the Systems Engineering Center ON Semiconductor. Stefan joined ON Semiconductor in 2013. Previously, he spent eight years at Siemens PSE as ASIC/FPGA designer where he developed digital solutions targeted for various areas, among others communications, power conversion and motor control. He spent also two years at Vacuumschmelze acting as inductive components designer and also took a role of product integrity engineer at Emerson Energy Systems responsible for verification of telecom power systems. Stefan has a master's degree in Applied informatics from the Faculty of Materials Science and Technology of Slovak Technical University Trnava.

Daniel Pruna is an applications section manager at the EMEA Systems Engineering Center at ON Semiconductor. Before joining On Semiconductor in 2019, he worked for nine years as development engineer and later as head of engineering for an OEM company in Germany. His work was mainly focused on battery chargers, switch-mode power supplies and motor controllers. Daniel holds an M.Sc. degree in Embedded Systems from Technical University of Chemnitz (Germany) and a B.Eng. from Lower Danube University of Galati (Romania).

Dionisis Voglitsis is an applications engineer at ON Semiconductor. He is responsible for the development and implementation of control algorithms and control schemes for motor control and charging applications. Before joining ON Semiconductor in 2019, Dionisis worked as a researcher for various European and national research projects, while he had also joined the Advanced Technology Center of Philips. Dionisis is the author and co-author of more than 30 research and technical papers in his field, published in high-quality journals (IEEE Transactions and Journals), which have been cited in more than 200 papers. He is also a guest editor for the "Energies" MDPI journal. He holds an engineering degree in energy engineering, an M.Sc. in wireless power transfer from TU Delft, The Netherlands, and a Ph.D. in electrical engineering from Democritus University of Thrace (DUTH), Greece.

Rachit Kumar is a senior applications engineer at the Systems Engineering Center at ON Semiconductor. Rachit joined ON Semiconductor in 2020. Rachit has been engaged for more than ten years on embedded software development focusing on motor control algorithms. Prior to joining ON Semiconductor, Rachit worked at Nanotec Electronics doing embedded systems development for low power BLDC and stepper motor controllers. Rachit has a master's degree in mechatronics from the University of Applied Sciences, Ravensburg-Weingarten, Germany.

Ali Husain is senior manager for Strategy and Corporate Marketing, focusing on power electronics. He has previously worked in Technical Marketing at Fairchild Semiconductor and International Rectifier in various roles for nine years. Ali has a bachelor of electrical engineering and a bachelor of economics from the University of Pennsylvania and a Ph.D. in electrical engineering from the California Institute of Technology.

For further reading on designing EV chargers, see the How2Power Design Guide, locate the Application category and select "Automotive".